Codes and Standards Enhancement Initiative
For PY2004: Title 20 Standards Development

Analysis of Standards Options For Evaporative Coolers

Prepared for:
Gary B. Fernstrom, PG&E

Prepared by:
Davis Energy Group
Energy Solutions
May 11, 2004

This report was prepared by Pacific Gas and Electric Company and funded by California utility customers under the auspices of the California Public Utilities Commission

Table of Contents

1 Overview 1
2 Product Description 1
2.1 Evaporative Cooling Principles 1
2.2 System Types 2
2.3 Applications 5
3 Market Status 7
3.1 Market Penetration and Sales 7
3.2 Sales Volume 7
3.3 Market Penetration of High Efficiency Options 8
4 Savings Potential 9
4.1 Baseline Energy Use 9
4.2 Proposed Test Method 9
4.3 Efficiency measures 10
4.4 Standards Options 10
4.5 Energy Savings 13
5 Economic Analysis 13
5.1 Incremental Cost 13
5.2 Design Life 13
5.3 Life Cycle Cost 14
6 Acceptance Issues 14
6.1 Infrastructure Issues 14
6.2 Existing Standards 14
7 Recommendations 15
7.1 Recommended Standards Option 15
7.2 Proposed Changes to the Title 20 Code Language 16
8 References 16

1 Overview

The Pacific Gas and Electric Company (PG&E) Codes and Standards Enhancement (CASE) Initiative Project seeks to address energy efficiency opportunities through development of new and updated Title 20 standards. Individual reports document information and data helpful to the California Energy Commission (CEC) and other stakeholders in the development of these new and updated standards. The objective of this project is to develop CASE Reports that provide comprehensive technical, economic, market, and infrastructure information on each of the potential appliance standards. This CASE report covers standards and options for evaporative coolers.

2 Product Description

2.1 Evaporative Cooling Principles

Evaporative cooling involves the evaporation of water in a non-saturated air stream for delivery to conditioned space. The greater the drybulb temperature and lower the relative humidity, the greater the potential for evaporative cooling. The cooling sensation experienced when a breeze evaporates perspiration from one's skin, is likely the most common human experience with evaporative cooling. Evaporative cooling for space conditioning applications combines a fan, a water supply, controls, and evaporative media through which the air travels to deliver cooled air.

Key evaporative cooling performance descriptors include saturation effectiveness and unit efficacy. Effectiveness is defined as:

$$e = \frac{t_{db} - t_s}{t_{db} - t_{wb}} \qquad \text{Equation 1}$$

Where: ε = Effectiveness (%)

t_{db} = Outdoor drybulb temperature

t_{wb} = Outdoor wetbulb temperature

t_s = Supply drybulb temperature

Direct evaporative systems, which pass outdoor air through wetted media, typically achieve an effectiveness of 70-80%, while Indirect/Direct systems (see Section 2.2) can achieve an effectiveness of over 100%.

Evaporative cooling supply air temperatures are affected by both outdoor dry and wet bulb temperatures. Dry bulb temperatures are commonly reported values that are typically measured using mercury-bulb or digital thermometers. Wet bulb temperatures can be measured directly by passing air over a wetted fabric that surrounds the bulb of a thermometer (this device is called a psychrometer) or calculated from measurements of dry bulb temperature and relative humidity. The greater the difference between dry and wetbulb temperatures (“wetbulb depression”), the greater the temperature drop achievable in an evaporative cooling process. For example, during a hot California valley summer day, with dry bulb and wetbulb temperatures of 105° and 65°F, respectively, a 75% effective direct evaporative cooler would deliver 75°F air[1]. In contrast to vapor compression air conditioners, which generally dehumidify indoor air, evaporative coolers add moisture to the supply air stream.

Unit efficacy is defined as the ratio of total unit power to the air flow rate at some defined static pressure and is typically given in units of cubic feet per minute (cfm) per Watt.

2.2 System Types

Single Stage Systems

Single-stage (direct) evaporative coolers generally combine a blower, a pump, an absorbent evaporative pad, and other components in a metal, fiberglass, or polymer cabinet that has an air intake and a supply air outlet. Water is recirculated by the pump from a sump in the bottom of the cabinet over the evaporative pad, and the blower draws in outside air, passing it through the moist pad and into the building to be cooled. Water lost through evaporation is replaced by the operation of a float valve (or a solenoid valve and float switch) that feeds in fresh water from a water supply. The direct evaporative cooling process is illustrated in Figure 1, and a single stage cooler is shown in Figure 3. Some single stage coolers do not use a pump but rotate the evaporative pads through a water bath. Rarely, a cooling pad is not used and the air is passed through a water spray. There are other variations on this theme, but the principal of operation is the same.

Because the continuous evaporation of water concentrates minerals in the sump water, some method of removing the minerals must be used. This is typically accomplished by either bleeding off a small percentage of the water that leaves the pump to a drain, or by periodically completely emptying the sump using a separate pump or electrically operated drain valve.

Two-Stage Systems

Indirect/Direct (two-stage) evaporative cooler designs add an indirect cooling stage upstream of the direct stage. The indirect stage, most commonly a plastic plate air-to-air heat exchanger, cools the outdoor air evaporatively, but without adding moisture (see Figure 2). The downstream direct stage further cools the air, in some cases to a temperature below the outdoor wetbulb temperature, resulting in an overall effectiveness greater than 100%. A two-stage cooling system is shown in Figure 4. Two stage systems deliver cooler and drier supply air than can be achieved with a single-stage cooler, but at the expense of some added fan and pump energy. Indirect-only evaporative coolers are sometimes used to pre-cool make-up air for larger commercial buildings, but are not addressed by this proposed standard.

There are currently two, two-stage products on the market. One "piggy-backs" a separate indirect module with its own sump, pump and fan onto a direct evaporative cooler and the other integrates the indirect and direct cooling components into the same package. A third product that is under development (shown in Figure 4) uses a single

[1] 105 – 75% of (105 – 65) = 75

blower and splits the air stream between a "wet" path through one side of the heat exchanger, and a "dry" path through the other side of the heat exchanger, where it is indirectly cooled.   This system also includes a single sump and pump, high efficiency variable speed blower motor, and automatic control of sump mineral concentration.

Performance of two-stage systems can be characterized either by their indirect and direct effectiveness or by an overall evaporative effectiveness for the two stages. Overall effectiveness can be used to compare single and two-stage systems and is a preferred metric for standards purposes.

Figure 1:

Direct (single-stage) Evaporative Cooler Airflow Path

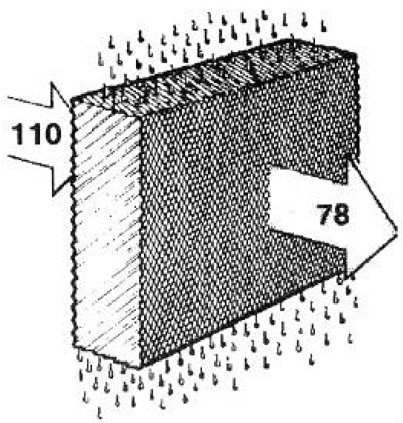


Figure 2:

Indirect-Direct (two-stage) Evaporative Cooler Airflow Paths

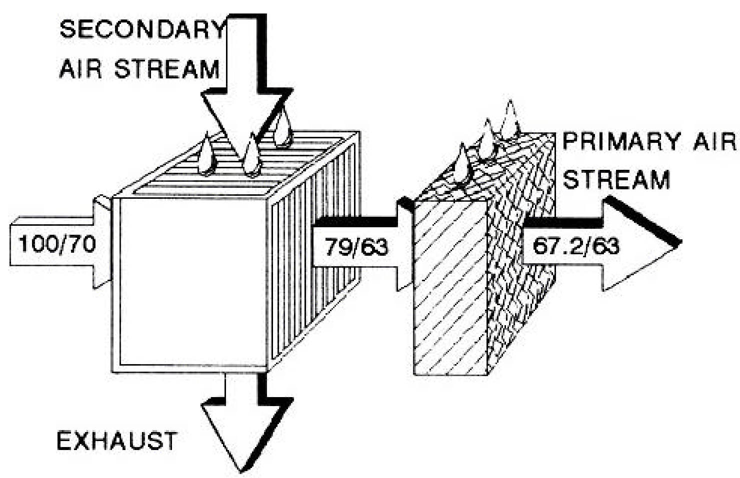


Figure 3:

Typical Direct Evaporative Cooler

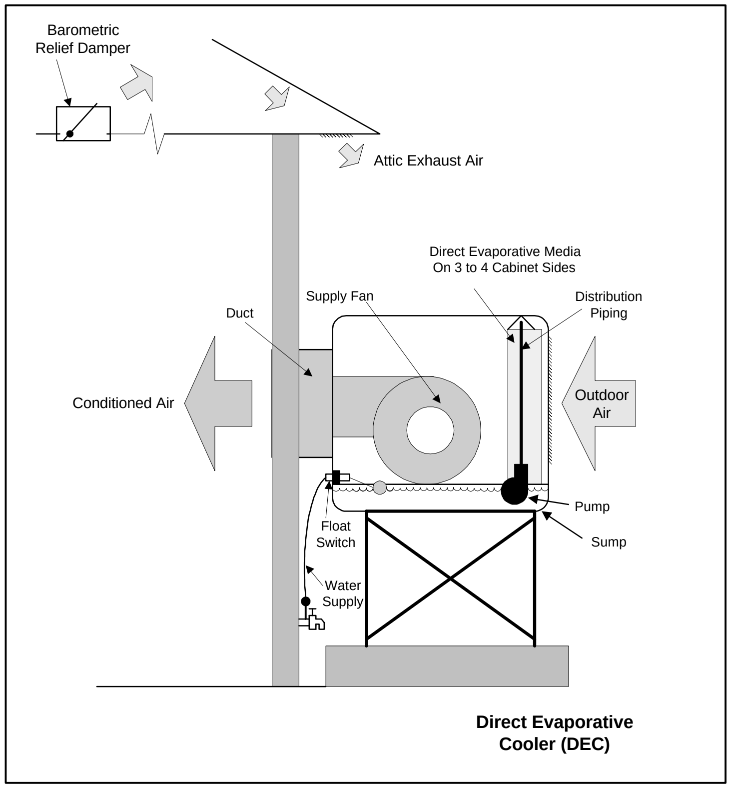
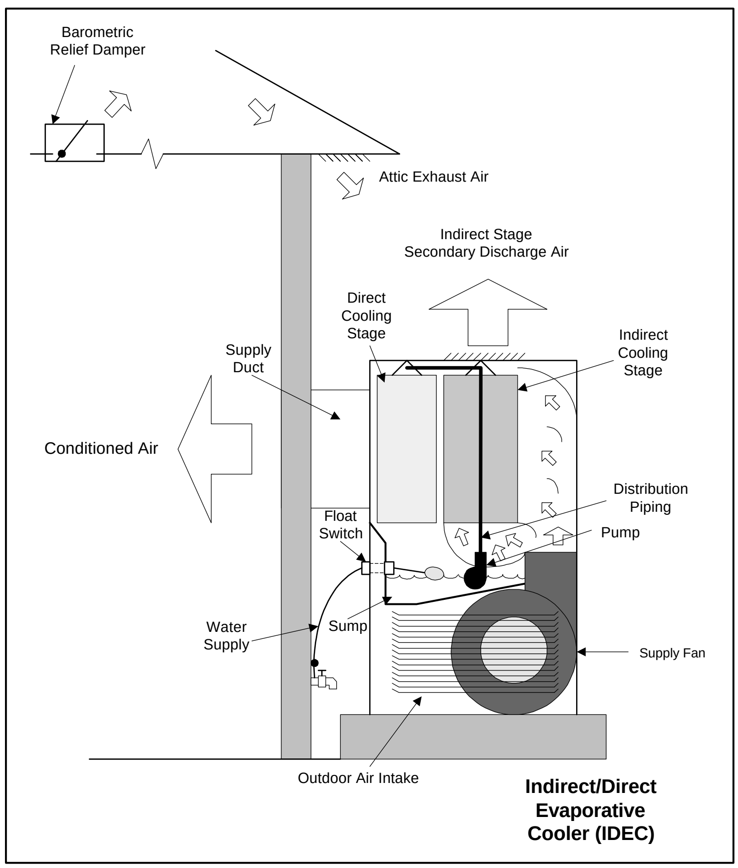


Figure 4:

Indirect/Direct (two-stage) Evaporative Cooler with Single Blower



Portable and Spot Coolers

Several manufacturers offer portable or spot coolers that are designed to deliver cool air directly on the work area. These do not connect to an outside air supply and therefore are not appropriate for general building cooling since they would eventually add moisture until indoor air reaches saturation. The proposed standard would not apply to these products.

Evaporative Media.

Cooler effectiveness depends largely on the capability of the evaporative pads or "media" to provide a high wetted surface area and minimal airflow resistance. Many materials have been used for media, including natural and synthetic fabrics; wood excelsiors; glass fibers; copper, bronze or galvanized screening; vermiculite, perlite, expanded paper, and woven plastic. Prior to the advent of rigid cellulose media, "aspen pads" were the standard for production coolers. This material is made from aspenwood excelsior from young trees grown at altitudes above about 10,000 feet to avoid a fungus commonly found at lower altitudes. Aspen pads generally cool supply air to lower temperatures than competing materials, but have a short service life due to sagging, clogging and decay. A woven, expanded paper product has gained popularity as a replacement for aspenwood pads in many markets. This media has a longer useful life than aspenwood, but does not cool air as effectively.

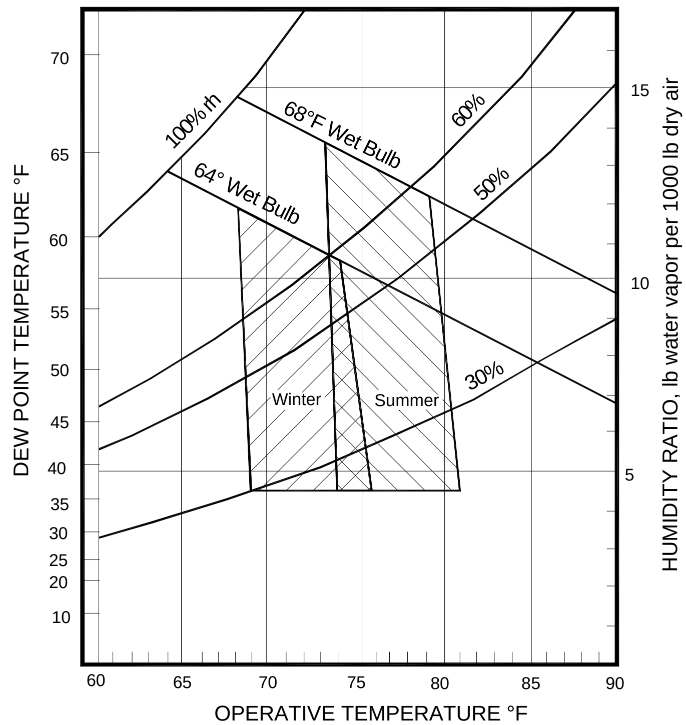
Developed in the 1960's, rigid media proved to be a landmark breakthrough due to its high performance and comparative durability. This cellulose or fiberglass content material is bonded in a cross-fluted design that induces turbulent mixing of air and water for improved heat and moisture transfer and self-cleaning. First introduced in large commercial and industrial applications, in recent years the material has been adopted by leading cooler manufacturers for use in premium quality products.

2.3 Applications

Evaporative coolers are used in residential, commercial, agricultural, and industrial applications where higher indoor humidity is acceptable and low operating cost is important. They can provide comfort equivalent to vapor compression cooling systems in dry climates, but during periods of hot, humid weather they may produce indoor conditions that are outside the ASHRAE "comfort zone" shown in Figure 5 and described in ASHRAE Standard 55-1992 (ASHRAE 1992). Since the temperature of the air they supply is proportional to the wet bulb temperature, the design wet bulb temperature published by ASHRAE for the building location is the best indicator of potential performance. Two-stage units provide a higher level of comfort, and can be used in more humid climates.

Figure 5:

ASHRAE Comfort Zone Chart



Common mounting locations for single-stage units include walls, roofs, windows, and ground equipment pads. They will not function properly if the building is not supplied with a means of relieving indoor air to the outside. The preferred method of relief is to install barometric dampers in the ceiling or walls. Open windows or doors are frequently used for relief with low cost wall/window-mounted systems, and agricultural/industrial systems. Ceiling-mounted relief dampers in houses with attics have the advantage of cooling the attic as well as the house, reducing ceiling heat gain.

Manufacturers generally tend to oversimplify sizing methods by specifying an airflow rate that corresponds to a particular location or design wet bulb temperature. More accurate techniques calculate building cooling load exclusive of latent and infiltration loads, and specify a system that will deliver a sufficient volume of air to meet the design load based on the corresponding design supply air temperature and the desired indoor air temperature. The supply air temperature is calculated from the system effectiveness and the design wetbulb temperature as indicated in Equation 1. Latent cooling load can be ignored because all air is exhausted; infiltration load can be ignored because the evaporative cooler pressurizes the building.

Evaporative coolers are typically controlled using manual switches, timers, and thermostats. Their low operating cost and relatively low cooling capacity favor the use of low cost controls rather than the setback thermostats used with vapor compression cooling systems. Some evaporative coolers have two fan speeds or fully variable fan speed control, allowing the user to control the temperature to some extent via the supply airflow, making the capacity of these units variable.

3 Market Status

Although evaporative cooling is relatively well suited to California's hot, dry climate, direct evaporative cooling comprises a small fraction of the market, and market share of two-stage coolers is so small as to be immeasurable (Mast 1999). Evaporative cooling market data is sparse. The sole industry association, the Evaporative Cooling Institute (ECI), is a small organization and does not maintain market data. Appliance Magazine, normally a good data source, does not include evaporative coolers in their statistics. The 2003 Air Conditioning, Heating & Refrigeration News Product Directory lists 31 manufacturers, five of which are identified as manufacturers of residential systems. Many of these manufacturers may serve specialty markets that are not related to providing human comfort.

A national survey of manufacturers conducted by E Source in 1998 provides the most complete compilation of manufacturers of evaporative space cooling equipment. Forty-one companies were identified which collectively produce packaged and custom direct, indirect, and indirect/direct equipment ranging from 1,000 to 1,000,000 CFM. Only four of the forty-one firms listed manufacture residential as well as commercial/ industrial equipment. Three of the four residential manufacturers are headquartered in Arizona.

3.1 Market Penetration and Sales

End use surveys completed by Southern California Edison (SCE) and Pacific Gas and Electric (PG&E) show that market saturation is higher in Southern California (9.4 percent in SCE territory) than Northern California (5.3 percent in PG&E territory). Applying the SCE and PG&E saturations to the 11.5 million California households (US Census 2000) suggests the number of EC's in operation statewide is near one million. In 1996, the California Energy Commission estimated that evaporative coolers were used in about 8% of California homes including 37% of California's 570,000 mobile homes. According to the Evaporative Cooling Institute, the national market totals about $180 million in annual commercial and residential sales.

3.2 Sales Volume

With vapor compression cooling becoming less costly, significant growth of the California evaporative cooling market is unlikely without program support. The popular perception that air conditioning is "good" and swamp coolers are "bad" exacerbates the need for incentive and educational programs to popularize the benefits of evaporative cooling. According to the Energy Information Administration (EIA), by 1993 72% of U.S. homes had some form of air conditioning, with nearly 50% provided by central systems. EIA data for 2001 show that evaporative coolers are found in only about 3% of the houses in the Pacific region, down from 7% in 1990 (EIA 2002; EIA 1990).

The majority of current sales are probably replacements. If there are 1 million evaporative coolers in California and they have a lifetime of 10 years, then annual sales would be slightly in excess of 100,000. The replacement market is hampered by the fact that retrofit of homes with existing air conditioning systems is made difficult by the size and location of the existing ducts. Evaporative coolers generally deliver greater air volumes than air conditioners, and backdraft dampers must be installed if ducts are shared by heating and evaporative cooling systems. Most evaporative coolers are not appropriate for installation in indoor closets, garages, and attics, where refrigerant cooling coils are typically located.

Water use has become a significant issue in some areas of the country. For example, in an effort to conserve water (and perhaps, sell electricity), El Paso Water Utilities and El Paso Electric are jointly offering a $300 cash incentive to customers who replace existing evaporative water cooling systems with central refrigeration cooling systems. Water use is dependent on several factors, including the method used by the cooler to refresh water and prevent scale, outside air temperature, and cooler operating hours. Systems that bleed a percentage of the recirculated water are not allowed in PG&E's rebate program because of their greater water use and tendency to maintain higher dissolved solids and increased scaling. Systems that use a pump or drain to refresh the water generally use less water and are approved for the program. In three monitoring studies of indirect/direct units completed by Davis Energy Group (DEG 1993; DEG 1995; DEG 1998), water use ranged from 3 to 27 gallons per hour, and averaged 7.6 gallons per hour, or approximately 3200 gallons per cooling season (at 420 hours of operation). This usage translates to an annual cost of roughly $11[2]. Reduction of generating plant condensing water consumption should be considered by any jurisdictional body seeking to restrict evaporative cooler installations on the basis of water use. The water savings indirectly associated with less power production will offset to some extent the water used directly in evaporative coolers.

According to Mast (1999), market barriers relating to performance uncertainties appear to be the most important market impediment. These barriers are partly attributable to negative associations with evaporative cooling, and partly to true shortcomings, suggesting that technology improvements may still be needed before the current market share can be expected to increase.

3.3 Market Penetration of High Efficiency Options

"High efficiency" must be carefully defined for evaporative coolers because both unit efficacy and saturation effectiveness must be considered (see Section 4.4). Two-stage coolers have higher effectiveness, but use more energy and therefore have a poorer unit efficacy.

Though a few products are known to have high evaporative effectiveness, the efficacy of coolers is not generally known. Low cost single-stage units such as those sold by big box retailers may have an efficacy that is similar to higher cost, high quality products, but they are not as capable of providing comfort because they deliver air that has a higher enthalpy (more humid and/or warmer). Lacking market share data from manufacturers, market penetration estimates of high efficiency products is difficult to estimate. The PG&E Rebate Program, which provides incentives for high efficiency evaporative coolers, has gathered some market data; they report that 289 rebates were issued for evaporative coolers during 2003. The long-term sales potential for high quality advanced (rigid media single-stage and two-stage) evaporative cooling products offering

---

[2] The combined cost for water and wastewater is about $3.50 per 1000 gallons according to the AB970 2001 working papers.

satisfactory comfort, and energy savings in the range of 70% to 80% (relative to vapor compression air conditioners) could be very substantial; however, considerable consumer education would need to be provided for it to be realized.

4 Savings Potential

4.1 Baseline Energy Use

The 1997 PG&E Residential Energy Survey Report estimates unit energy consumption for evaporative coolers at 479 kWh per year (PG&E 1997). This value is most likely a mix of window/wall units and roof-mounted whole house units. This compares to 456 kWh for window/wall air conditioning, and 1,364 kWh per year for central air conditioning.

4.2 Proposed Test Method

An "industry standard" airflow rating is used by some manufacturers as a comparative measure and sizing aid, but reported ratings are usually greater than the airflow rating at 0" w.c. Manufacturers have indicated this rating is not based on testing, but on an arbitrary assignment and has little relation to actual delivered airflow[3]. Some manufacturers have used ANSI/AMCA 210-99 test methods to rate their systems for airflow. An Australian standard, AS 2913-2000 "*Evaporative airconditioning equipment*" specifies test procedures and performance ratings for evaporative coolers. In addition to test procedures for air flow, evaporation efficiency, sound, and electric consumption, it includes an appendix A describing the calculation of rated cooling performance. ASHRAE Standard 143-2000 describes a method for rating indirect evaporative coolers only. ASHRAE also recently published Standard 133-2001 titled "Method of Testing Direct Evaporative Coolers". Although it specifically addresses direct (one-stage) coolers, there is nothing about the method that would prevent its use for two-stage direct/indirect coolers. It can be used to report overall (direct + indirect) effectiveness at rating conditions, and would account for the lower delivery temperatures provided by two-stage coolers.

ASHRAE Standard 133-2001 test method specifies that results will be reported as performance curves using airflow rate as the abscissa, and will plot as ordinates the standard static pressure differential, standard power input, and standard saturation effectiveness. Standard rating assumptions can be assigned to indoor temperature and outdoor dry bulb and wet bulb temperatures enabling an energy efficiency ratio (EER) to be calculated using Equation 2.

$$EER = \frac{1.08 \times (t_{in} - (t_{db} - e(t_{db} - t_{wb}))) \times Q}{W} \qquad \text{Equation 2}$$

Where: t_{in} = standard indoor dry bulb temperature

[3] Information obtained at a meeting of evaporative cooler manufacturers at the PG&E Stockton Training Center, November 14, 2003.

t_{db} = standard outdoor dry bulb temperature
t_{wb} = standard outdoor wet bulb temperature
ε = measured saturation effectiveness
Q = measured air flow rate (cfm)

W = measured total power (Watts)

Total unit power includes power used by fan motors, pump motors, and other devices needed to produce the cooling effect. Power for devices such as thermostats, transformers providing low voltage to control mechanisms, and freeze protection devices shall not be included in total unit power.

EER shall be calculated at the following conditions:

- airflow rate that corresponds to 0.3" external static pressure
- 80°F indoor temperature
- 91°F outdoor dry bulb temperature
- 69°F outdoor wet bulb temperature

The static pressure level is close to the 80Pa level specified by AS 2913-2000. The dry bulb and wet bulb temperatures represent an average of the 2% design wet bulb and mean coincident dry bulb temperatures for eight California cities[4].

4.3 Efficiency measures

Manufacturers seldom publish effectiveness or power draw, and no test data is available for single stage coolers. Estimates place the saturation effectiveness of flexible media units at between 55% and 75% (Sohr 1994), and rigid media systems at up to 90% (Munters 2002). Blower motors are typically low efficiency split phase with efficiencies in the range of 50-60%. Monitored EER's ranging from about 19 to 58 were measured for two-stage AdobeAir units[5], which have a theoretical effectiveness approaching 100% (SMUD 1992).

From Equation 2 it is clear that efficiency (EER) can be improved by raising the saturation effectiveness and/or by raising unit efficacy. The former can be accomplished by using higher performance media such as the rigid media currently used in several systems. Unit efficacy can be improved by using more efficient blowers, blower motors, pumps, and/or reducing internal pressure drop by improving aerodynamics.

4.4 Standards Options

Options for implementation of an evaporative cooling standard include unit efficacy, saturation effectiveness, and EER. Unit efficacy can be determined using either ANSI/AMCA 210-99 or ASHRAE 133-2001, and saturation effectiveness must be determined using ASHRAE 133-2001, which can also be used to identify EER. An EER calculation would prove useful for comparing performance of evaporative cooling to vapor compression air conditioning.

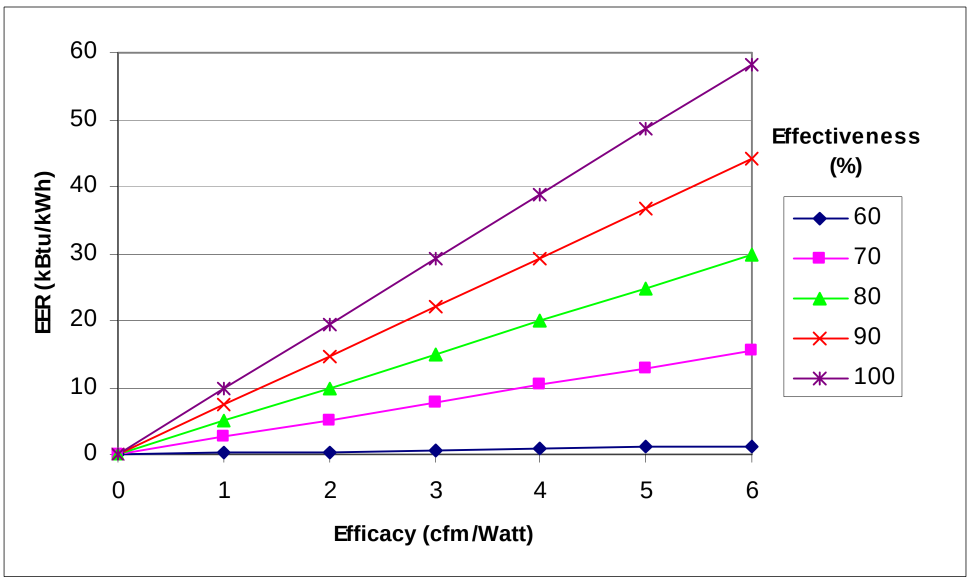
---

[4] Bakersfield, Fairfield, Fresno, Ontario, Riverside, Red Bluff, Sacramento, and San Jose.
[5] This wide range of EER's was primarily a result of differing indoor temperature settings and its resulting impact on calculated EER.

Evaporative cooler capacity is strongly a function of outdoor dry bulb and wet bulb temperatures. The ASHRAE Fundamentals Handbook publishes design conditions for both "cooling", which is based on the design dry bulb and mean coincident wet bulb temperatures, and "evaporation", which is based on the design wet bulb and mean coincident dry bulb temperatures. Use of the "evaporation" design temperatures in sizing calculations typically results in larger equipment sizes than when "cooling" design temperatures are used.

Figure 4 plots the relationship between EER, effectiveness, and efficacy using Equation 2 for outdoor conditions of 91°F dry bulb and 69°F wet bulb, and at an indoor temperature of 78°F. Figure 4 shows that, under these conditions, a cooler with an effectiveness of less than 60% cannot deliver air cooler than the 78° indoor temperature. Systems using expanded paper have a saturation effectiveness ranging from 45 – 61%. Aspen media and rigid cellulose have saturation effectiveness's of about 73% and 75-84% respectively[6].

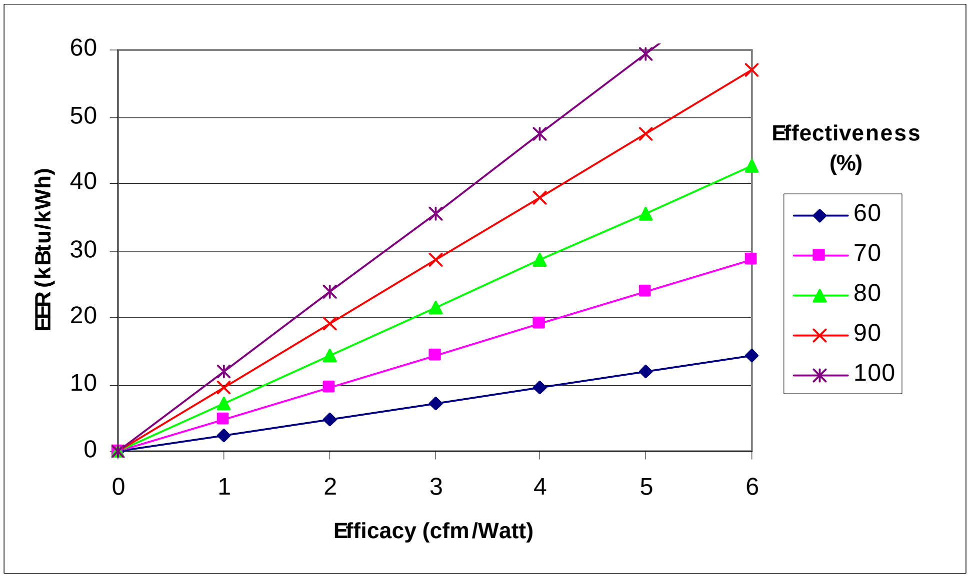
Figure 6: Evaporative Cooler Performance Map at 78°F Indoor Temperature, 91°F Outdoor Dry Bulb Temperature, and 69°F Outdoor Wet Bulb Temperature



An EER-based standard presents several dilemmas. Many commercial/industrial applications, including commercial kitchens where evaporative cooling is commonly used, have a higher indoor design temperature than 78°F. Figure 5 presents the same curves calculated at an indoor temperature of 80°F, and shows that a cooler with expanded paper media (60% effective) and a unit efficacy of 5 cfm/Watt would have an EER of about 12, while a similar cooler with aspen pads (75% effective) would have an EER of about 30.

[6] Roger Palmer, AdobeAir, e-mail communication to R. Michael Martin, California Energy Commission, 6/9/03.

Figure 7: Evaporative Cooler Performance Map at 80°F Indoor Temperature, 91°F Outdoor Dry Bulb Temperature, and 69°F Outdoor Wet Bulb Temperature



Another shortcoming of this method is that systems that vary airflow rate will have a higher average efficiency that will not be represented by a standard based on a single airflow rate. Several manufacturers offer two speed systems, and a fully variable speed system is under development. Variation in the quality of air delivered also complicates the rating of evaporative coolers. Since EER it is based only on the dry bulb temperature of the delivered air, it provides no indication of what indoor relative humidity will result, and whether indoor conditions will fall within the ASHRAE comfort zone.

Despite these limitations, EER is the best performance indicator that can be obtained from ASHRAE 133-2001 test data. A minimum EER of 15 calculated at an 80°F indoor temperature should be obtainable without imposing an undue hardship on the industry or the consumer, and would result in evaporative equipment that is at least 30% more efficient than a new vapor compression air conditioner at evaporative design conditions[7]. Under dryer peak day conditions, the efficiency benefit of evaporative cooling would improve.

[7] A vapor compression air conditioner that meets the forthcoming federal air conditioning standard of 13 SEER would have an EER of ~11.5 at 91°F outdoor conditions.

4.5 Energy Savings

Based on typical summer design conditions[8] and assuming an evaporative cooler with expanded paper and a blower motor with an efficacy of 3 cfm/Watt, substituting aspen and rigid media would result in an increase in EER from 11 to 16 and 32 respectively. However, because total unit power use is relatively constant, this increase in efficiency does not translate directly into energy savings because run time may not drop proportionally. Assuming that one third of the savings are lost to lower indoor temperatures and/or improved comfort, this would result in a 21% and 44% reduction in energy use for aspen and rigid media respectively. This savings estimate is conservative, as it is reduced under the presumption that additional comfort will be provided. If normalized for constant comfort, the savings would be even greater. Using a higher efficiency PSC blower motor would increase efficacy by 10%, all of which would translate into energy savings. These savings are extrapolated to state-wide savings in Table 1, based on the estimated evaporative cooling stock of 1 million units and sales of 100,000 per year.

Table 1: Potential Energy Savings

Measure	*% Improvement*	*Per unit Savings (kWh/year)*	*First Year Savings (GWh/year)*	*Statewide Potential Savings (GWh/year)*
Aspen Pad	21%	103	10	103
Rigid Pad	44%	209	21	209
Improved Motor	10%	48	5	48

5 Economic Analysis

5.1 Incremental Cost

Aspen pads are assumed to be $4 more than expanded paper. Upgrading from expanded paper to rigid cellulose media would cost about $6 per square foot, increasing the cost of the media by about $46. Using an increased efficiency PSC blower motor would increase costs by $6 (DOE 2002).

5.2 Design Life

The design life of an evaporative cooler varies as a function of its design, application, and especially the quality of the water. Most inexpensive coolers have an expected life of about 10 years. Evaporative media is considered an expendable material, much the same as furnace filters. Expanded paper media lasts about one year and aspen media may last two years, whereas rigid cellulose media may last over five years, so that improving efficiency also results in improved service life.

---

[8] At 99°F outdoor drybulb, 67°F outdoor wetbulb, and 80°F indoor drybulb

5.3 Life Cycle Cost

The effect on net customer present value for replacing expanded paper media with aspen and rigid media, and improving the blower motor are summarized in Table 2. Maintenance labor costs are ignored in this analysis for simplicity.

Table 2: Analysis of Customer Net Benefit

Measure	*Design Life (years)*	*Annual Energy Savings (kWh)*	*Present Value of Energy Savings**	*Incremental Cost*	*Net Customer Present Value***
Aspen Pad	2	103	$28	$4	$24
Rigid Pad	5	209	$112	$46	$66
Improved Motor	10	48	$44	$6	$38

*Present value of energy savings calculated using Life Cycle Costs from (CEC 2001).
**Positive value indicates a reduced total cost of ownership over the life of the appliance

6 Acceptance Issues

6.1 Infrastructure Issues

The phasing out of media with low effectiveness and replacement by higher quality media may create temporary supply problems that could be mitigated by allowing at least a one-year delay on implementation of the standard. Minor changes in manufacturing processes may be required due to the added thickness of higher quality media. Rigid media may add 3” or more to the thickness.

Test facilities that perform testing in accordance with ANSI/AMCA 210-99 have much of the equipment and capabilities needed to complete ASHRAE 133 tests, but an investment in equipment for measuring and maintaining temperature and psychometric conditions would be required.

6.2 Existing Standards

There are no mandatory standards in existence for evaporative coolers in the U.S, although safety testing (UL or ETL) may be required by most building jurisdictions. Australia has been considering a performance standard but for the present has rejected this move on the basis that it would “fail to meet the prerequisite cost benefit requirements for national law making” (NAEEEP 2001). They are continuing to seek input from stakeholders on methods to improve evaporative cooler efficiency.

Under the present California Title 24 Standards, direct or indirect/direct evaporative coolers may be used with any residential compliance approach subject to the eligibility and installation criteria listed below. Energy credits assume an 11 equivalent SEER for direct systems, and a 13 equivalent SEER for indirect/direct systems. Although evaporative coolers can achieve efficiencies much greater than these, there is a valid concern that allowing credit for higher efficiencies would result in a trade off with more persistent measures, and that the evaporative coolers could be replaced by air conditioners when they fail.

No code change proposals were put forth on behalf of evaporative coolers for the 2005 Title 24 standards rulemaking. The Energy Commission is considering conducting research that may lead to changes to the evaporative cooler compliance option for the 2008 standards. Section 4.5.3 of the Residential Manual states the following:

Title 24 Eligibility and Installation Criteria:

1. Credits are allowed for single-family detached or attached residences, but not for multi-family buildings.
2. Evaporative cooler ducts, if any, must satisfy all requirements applicable to conventional air conditioning ducts.
3. Thermostat control is required. A two-stage thermostat with time lockout is required if second-stage or "back-up" conventional air conditioning is installed.
4. Automatic relief venting must be provided to the building.
5. Evaporative coolers must be permanently installed; credits are not allowed for portable window units.
6. Evaporative coolers must provide minimum airflows in accord with the Air Movement and Control Association (AMCA), Standard 210, shown in Table 3.

Table 3. Minimum Air Movement Requirements for Evaporative Coolers

	*Minimum Air Movement (cfm/sf)**	
Climate Zones	Direct	Indirect/Direct
1 – 9	1.5	1.2
10 – 13	3.2	1.6
14 – 15	4.0	2.0
16	2.6	1.3

* If backup air conditioning is installed, the minimum air movement for all climate zones is 1.0 cfm/sf.

If a Title 20 standard is adopted the values in Table 3 should be eliminated and sizing calculations substituted. Two-stage evaporative coolers, more likely to be installed in lieu of air conditioners in new homes, do not need to provide as much airflow because the supply air temperatures are lower.

7 Recommendations

7.1 Recommended Standards Option

The viability of a performance standard for evaporative coolers is supported by the availability of a test standard, the substantial potential for performance improvement, strongly favorable economics, and probable long-term support from a majority of stakeholders. The preferred standards option is an EER that is calculated from ASHRAE Standard 133-2001 under the following conditions:

- Saturation effectiveness and fan power measured at an airflow rate that corresponds to 0.3" external static pressure
- 80°F indoor temperature
- 91°F outdoor dry bulb temperature
- 69°F outdoor wet bulb temperature

However, setting an appropriate EER level without data on the performance of current evaporative coolers would impose an unknown burden upon manufacturers. Therefore, we only recommend requiring the testing and listing of evaporative coolers at this time. By making available performance ratings that are analogous to air conditioner ratings, standards would facilitate consumer choices and may improve the market share of evaporative cooling. Since higher EER's are most easily attained by improving saturation effectiveness, selection of high EER systems by consumers would contribute to improved indoor comfort and greater acceptance.

7.2 Proposed Changes to the Title 20 Code Language

The following standards language is proposed for Table U in section 1606:

Evaporative Coolers	Evaporative Media Saturation Effectiveness (%)	
	Total Power (Watts)	
	Airflow Rate (CFM)	
	EER	
	Media Type	Expanded Paper, Woven Plastic, Aspenwood, Rigid Cellulose, Other

8 References

AdobeAir, 2000 WhisperCool, MasterCool evaporative cooling products data website. www.adobeair.com.

ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1992.

2001 ASHRAE Handbook, Fundamentals. American Society of Heating, Refrigeration, and Air Conditioning Engineers. 2001.

Bourne, R. 1998. Evaporative Cooling, Natural Cooling for Dry Climates, E Source Technical Update, 1998.

BSRI/ASHRAE Standard 133-2001, Method of Testing Direct Evaporative Air Coolers, American Society of Heating, Refrigerating and Air-Conditioning Engineers, February 2000

Cler, G., M. Shephard, et al. 1997. *Commercial Space Cooling & Air Handling Technology Atlas*. E Source.

Construction Industry Research Board (CIRB), 2001. California Statistical Abstract – 2001, Table I-5, http://www.cirbdata.com.

County/State Population and Housing Estimates, January 1, 1994, Official State Estimates, California Department of Finance, Demographic Research Unit

Davis Energy Group. 1993. SMUD Indirect/Direct Evaporative Cooler Monitoring Report. Project report to the Sacramento Municipal Utility District.

Davis Energy Group. 1995. Indirect/Direct Evaporative Cooler Monitoring Report. Project report to Pacific Gas & Electric Company.

Davis Energy Group. 1995. Indirect-Direct Evaporative Cooler (IDEC) Development Project Final Report. Project report under the California Energy Commission Energy Technology Advancement Program.

Davis Energy Group. 1995. Coachella Valley Energy Showcase Project - Palm Springs Site. Sub-project report to Southern California Edison.

Davis Energy Group. 1998. Field Evaluation of Residential Indirect-Direct Evaporative Cooling in PG&E's Transitional Climates. Project report to Pacific Gas & Electric Company.

[DOE] 2002: Furnaces and Boilers Standards Rulemaking, Draft Report for Review, Engineering Analysis, Building Technology Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, September 19, 2002.

EIA, Residential Energy Consumption Survey, Appliances in Pacific Households,Table D9, www.eia.doe.gov/emeu/reps/appli/pacific_table.html.

Evaporative Cooling Market Study, Davis Energy Group for ACMA Technologies Pte. Ltd., 2000

Huang, J. and H. Wu. 1992. Measurements and Computer Modeling of the Energy Usage and Water Consumption of Direct and Two-Stage Evaporative Coolers. Proceedings, 1992 ACEEE Summer Study.

Hydronic Specialties Company. 1998. *Cooling the 21st Century…it gets better*. Product brochure for the IDAC "SmartCool".

Mast, B., et al. 1999. Evaporative Cooling in California: Assessing the Market and Establishing Baselines for Evaporative Cooling Technologies in the Residential and Commercial/Industrial Sectors. www.aesp.org/EvapCooling.pdf

Munters Corporation Technical Bulletin, *5090 Evaporative Cooler Pads*.

Munters Corporation Engineering Bulletin EB-PS101-0201, *Learning to Use the Psychometric Chart.* Munters Corporation 2002.

NAEEEP, 2001. Minimum Energy Performance Standards, Evaporative Coolers. National Appliance and Equipment Energy Efficiency Program. Australia, March 2001. (http://www.energyrating.gov.au/library/pubs/profile-evapac2001.pdf)

Pacific Gas & Electric Company. 1997. *Residential Energy Survey Report*.

Sohr, R.T. 1994. Evaporative Cooling in High Wet-Bulb Climates. ADA Systems, Wood Dale, IL.

US Census Bureau (US Census), 2000. General Housing Characteristics: 2000, http://factfinder.census.gov.

Watt, J.R., et al. 1986. *Evaporative Air Conditioning Handbook, Second Edition*. Chapman and Hall Publishers.